An Improved Rotary Singulator

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ABSTRACT

A new operating approach for a previously existing rotary singulator was developed which improves the versatility of the device. This was accomplished by the implementation of a modular mechanism that performed the basic functions of agitation, gating, pocket formation, and exit, all inherent in this type of singulation device.

INTRODUCTION

Many operations in food processing industries require that items to be processed be supplied singly or in some other ordered fashion. Usually, however, the initial supply of items is in a disorganized bulk state. The act of ordering objects from a disorganized state to an ordered one is called singulation (Henderson and Shawver, 1973).

Until recently, singulation has not been treated formally as a research or major design area. Much of the information published on singulation devices are simply patents (Shawver and Henderson, 1972). For the most part, singulation has been addressed as a second-order problem; that is, after a downstream process has been designed the method of feeding it is considered.

Our research interest in singulation stems from the fact that in many processing operations it is a major trouble spot and is the limiting factor in some. It is not uncommon to see such machines as peach pitters operating at 60% efficiency simply because the singulation device could not adequately supply them. In addition to inadequate singulation, it is common to see immense and mechanically complex singulators consisting of hundreds of feet of conveyor belting and large supporting structures. There is economic motivation therefore to develop efficient, compact, and reliable singulation devices and systems.

In an effort to help design efficient singulators, an analytical technique for the analysis and synthesis of singulation methods has been suggested (Shawver and Henderson, 1973a). This technique was then used to develop a new device called an Undulating Surface Singulator by Shawver and Henderson (1973b). Later, Yong and Henderson (1979) developed a novel rotary singulator. This was an attempt to design a machine that could fulfill the need in the food processing industry for a faster and more efficient singulator to handle common produce. Even though a patent was granted for this device, and reviewers agreed that the singulator was new and novel, the design would have to be made more versatile to become attractive. Versatile here means that a machine, by easy adjustment, should be able to handle a useful range of sizes of a commodity or commodities.

The purpose of this project was to enhance the design of the previously existing rotary singulator. The enhancements were primarily intended to allow the singulator to easily adjust to accommodate different sized commodities as well as different types of commodities while still maintaining the outstanding qualities of the previous rotary design (Furman, 1982).

PRELIMINARY STUDY

From a study of previous work four important sub-problem areas became clear: (a) Agitation, (b) Gating, (c) Pocket Formation, and (d) Exit. Agitation refers to the fact that discrete objects will tend to "bridge" amongst themselves rather than flow in a behaved consecutive order and hence must be disturbed in order to maintain a flow. Gating denotes the accepting of a specified number of articles and the denial of more than this number. Pocket formation is used to mean the establishment of a physically defined region where the specified number of gated articles temporarily reside. Exit refers to the means whereby the specified number of articles in the pocket are released from the singulator in an ordered state to another device in the handling process.

These areas may be visualized in the photograph of Yong and Henderson's singulator (Fig. 1). The triangular pieces perform the agitation, gating, and pocket functions. They rock back-and-forth about the fixed vertical shafts through their centers as the singulator surface rotates. The rocking motion of the triangular vertices serve to break up bridges of articles trying to move radially outward to the driving belt at the edge of the turntable. The vertices also allow the passage of only one article between them at a time and they help define the pocket region along with the upstanding rectangular walls. The belt performs the exit function by allowing the articles to leave the pockets in consecutive order.

Unfortunately, the means by which the gating and pocket functions are performed in this singulator is not versatile. The rigid fixation of the rocker shafts and pocket walls makes adjustments for variations in object size very difficult. Also, there is a chance that soft objects could be damaged if caught in between the rocker pairs.

Each of the four sub-problem areas identified in the morphological analysis were addressed separately, and schemes to perform each function were devised.

One idea that highly influenced our design dealt with the pocket function. Fig. 2 shows the idea of pocket walls, that, over a specified rotation angle β, would form

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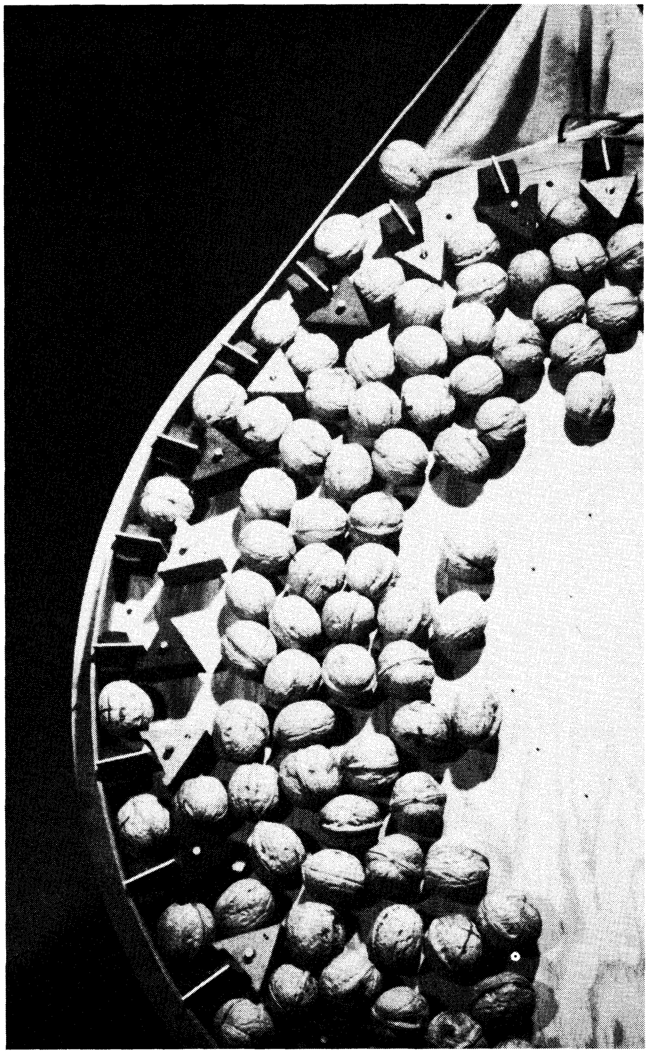


Fig. 1—Original rotary singulator.

and then disappear; actual vertical surfaces between articles are not shown in the figure. Over the angle θ, agitation would accompany the pocket formation, thus destroying bridges and "ordering" the objects as shown.

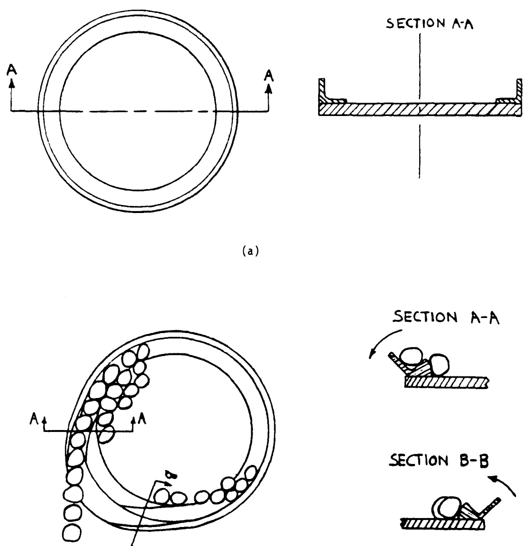


Fig. 3—Flexible peripheral wall.

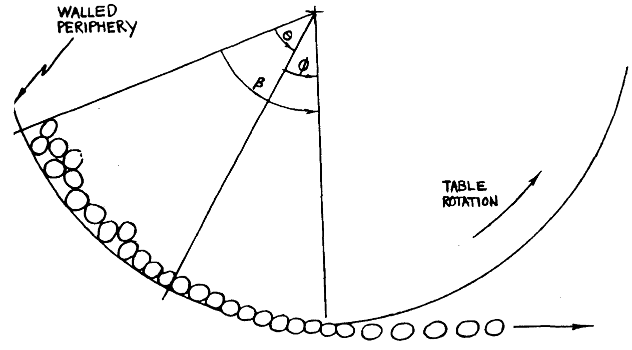


Fig. 2—Use of temporary pocket walls.

Over another angle ϕ, the pocket would disappear and the ordered objects would be allowed to exit. The exiting objects would then be in a single file line moving tangent to the exit point. This concept of using no permanently fixed pocket walls was attractive because of its potential versatility. Instead of being stuck with unadjustable walls, this device would allow the objects themselves to define the "pocket". Size variation in objects would not be a problem here.

With numerous schemes for accomplishing each function independently of the others, ideas were then developed that tried to integrate the four functions. One significant idea combined the forming and disappearing pocket walls with ideas for gating and exit and is shown in Fig. 3a. A continuous, flexible, circumferential, L-shaped channel forms the peripheral wall. Over some angle of the table rotation, the channel cross-section is twisted through 90 deg and then returned to the upright position as shown in Fig. 3b. The curved part of the channel cross-section blocks out additional articles, thus performing the gating function. As the channel twists 90 deg, the articles are free to exit.

A refinement to this idea quickly came which lent itself to easier implementation than a flexible channel. This was to make the "channel" out of many, short, L-shaped

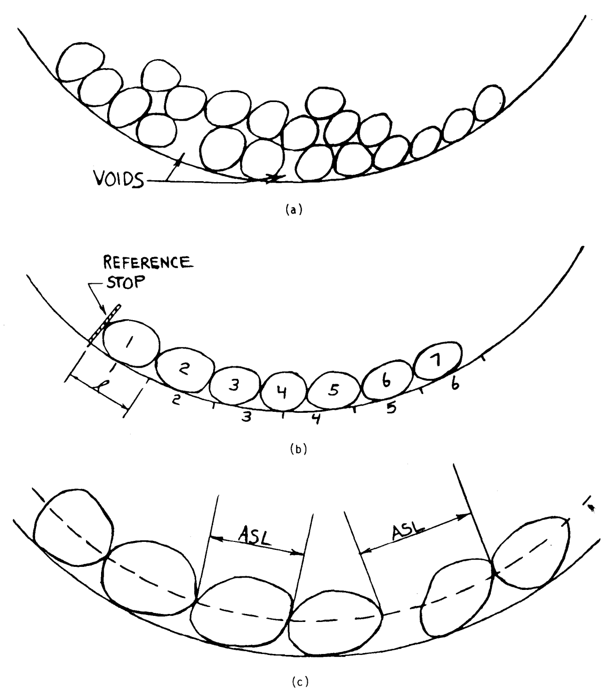


Fig. 4—Indexing study.

sections. The same 90 deg rotation could be generated, but in a simpler mechanical way.

Although the channel idea allowed great versatility, it presented a potential indexing problem. If the singulator were required to supply the next step in a processing line such as a pocketed conveyor belt, then how is synchronization maintained without fixed pocket walls. A void or variations in size as shown in Figs. 4a and 4b could cause indexing errors which would produce great problems for the downstream operation.

This motivated a study to determine how a collection of articles would index themselves at the periphery of a circular turntable. A turntable, 762 mm in diameter with a 51 mm high circumferential wall mounting on a rotatable shaft was constructed to serve as a model of the singulator. A conical surface was placed on top of the turntable to simulate the effect of rotation. It was decided at this time that English walnuts would be used as the test objects. Their characteristics of durability, long shelf-life, and irregular shape make them a desirable object for singulator development.

The test consisted of filling the turntable with approximately 100 walnuts having dimensions between 25.4 and 40.9 mm. A stop was attached to the wall to serve as a measurement or indexing reference point, Fig. 4b. The table was shaken about its axis of rotation three times to reduce voids. A Nominal Space Length (NSL), l, was determined by measuring the arc length along a fictitious idealized circle drawn through the mutual contact points of the objects and dividing by the number of objects residing along the arc length (Fig. 4c). An Actual Space Length (ASL) was measured as shown in Fig. 4c. The cumulative deviation, CD, was calculated as $CD = \sum_{i} (ASL_i - NSL)$, where i goes from one to the number of the last article (26) in the sample under test.

The conclusion from the indexing test was encouraging (Furman, 1982). The cumulative deviation was small, on the order of ± 6.4 mm; hence, a singulation device which relied upon the objects to space themselves and remain indexed would not experience a great indexing problem provided voids did not occur. The importance of agitation to destroy these voids was made vividly clear.

FIRST PROTOTYPE

Most design projects are iterative in nature; ours was no exception. An idea emerged from the circumferential channel concept and the indexing test results. This was to make the channel out of individual "modules", each of which would perform the four functions on the objects near it. Fig. 5a shows the final version of the modules mounted on the turntable.

These modules consist of two pieces connected with a rod that allows relative rotation between them. In their normal position, the modules together simply appear as an upright circumferential wall. When the table rotates to a certain point, a stationary cam surface causes the upright "wall" pieces of the modules to rotate about their pivot rods sequentially, thus creating a motion similar to the 90 deg rotation of the flexible, L-shaped channel of Fig. 3b. This rotation causes the lower, curved portion of the rotating piece to rise above the turntable surface, isolating the object closest to the wall from the rest of the objects, thus accomplishing the gating function (Fig. 5b). As the rotation occurs, a pocket is effectively formed between adjacent modules. When the wall has rotated 90 deg, the article in the pocket is free to move radially outward; hence, a single-file line of objects streams off the table as the module

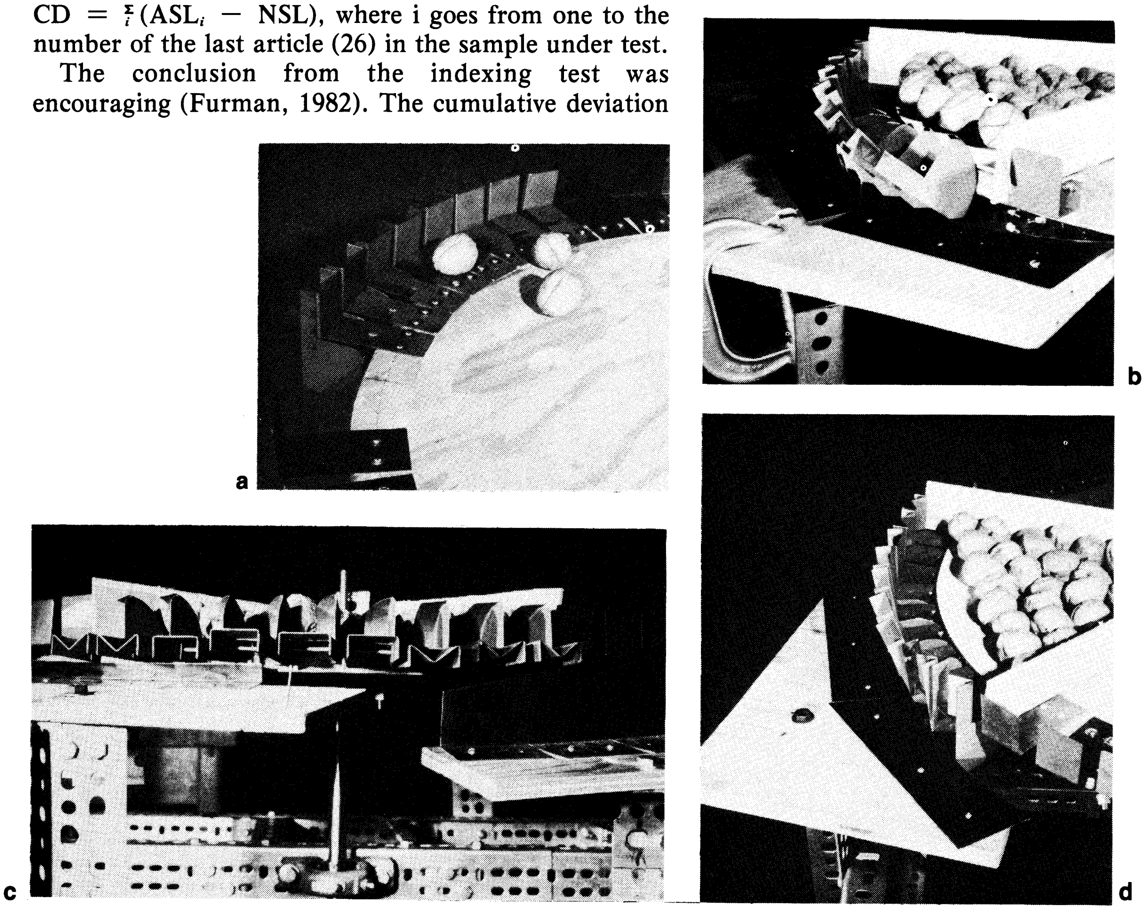


Fig. 5—First prototype.

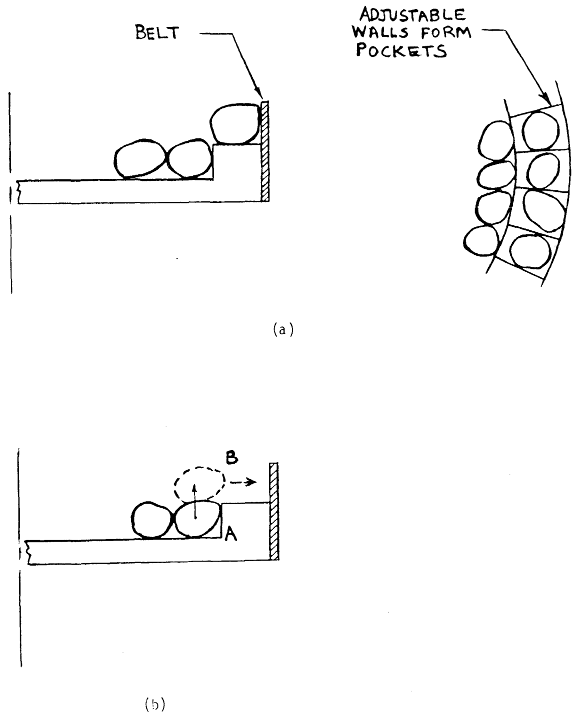


Fig. 6—Passive wall idea.

action proceeds consecutively. After the articles leave the pocket, another cam causes the module wall to return to its upright position. The 90 deg rotation is shown in Fig. 5c. In between the return and exit phase, agitation occurs. A cam surface causes a slight rotation of the wall piece which "nudges" the objects and tends to align one object directly in front of each module (Fig. 5d).

It should be noted that the circumferential spacing of the modules determines the pocket width, hence the size of object that can be singulated. The modular idea allows versatility because the module spacing can be altered by removing or adding more modules around the periphery of the singulator, thus increasing or decreasing the pocket width.

The results of the testing of this first prototype pointed to some rather blunt conclusions about the module

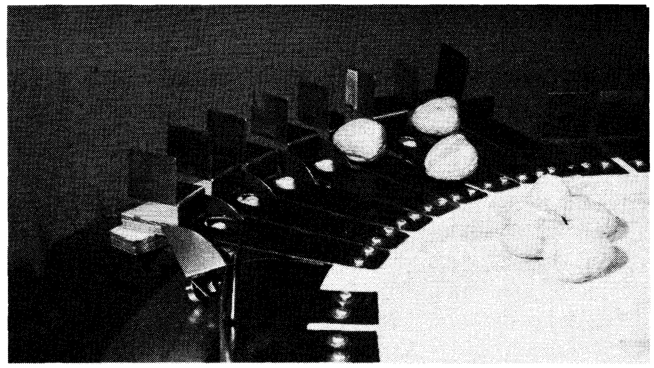


Fig. 8—Agitation.

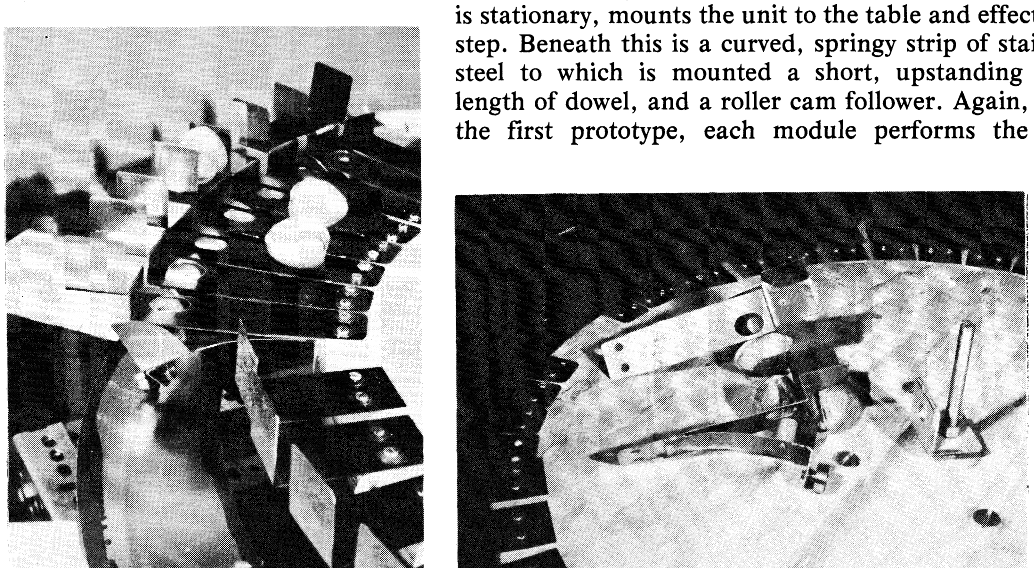
design. First of all, a persisting problem of multiple object exits was inherent in this type of module. It is evident that the walnuts respond very actively to vertical motion inputs and this is exactly the kind of impact provided by the action of the module in order to accomplish the essential gating and pocket functions. Second, this design does not fully utilize the dynamic effects of rotary singulation. Instead of creating a pocket from which the walnuts could move off the table by "centrifugal" force, the rising walls actually "forced" the walnuts off.

SECOND PROTOTYPE

Another idea capitalized on the walnut's tendencies shown in the previous design's evaluation. Instead of an active approach to perform the gating function, this second design uses a passive wall as shown in Fig. 6a. The wall, or step, isolates the second-row objects from the first-row objects in the exit position by placing them on different levels. The operation of the device is shown in Fig. 6b. The objects are raised from the table level at A to the height of the step at B. From point B, the object is urged by "centrifugal" forces to the pocket area. A flat belt (in cross-section) similar to the one used in Yong's singulator forms a peripheral wall and accomplishes the exit function in a similar manner.

This idea lent itself well to the modular approach also. Figs. 7a and 7b show the final version of this idea. Each module is composed of two major pieces. A base, which is stationary, mounts the unit to the table and effects the step. Beneath this is a curved, springy strip of stainless steel to which is mounted a short, upstanding wall, length of dowel, and a roller cam follower. Again, as in the first prototype, each module performs the four

a



b

Fig. 7—Prototye modules.

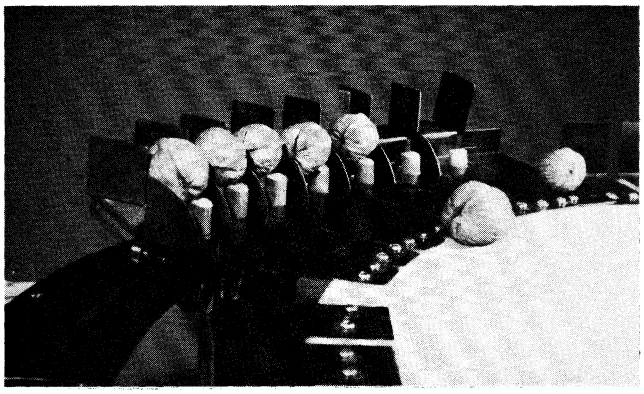


Fig. 9—Elevation.

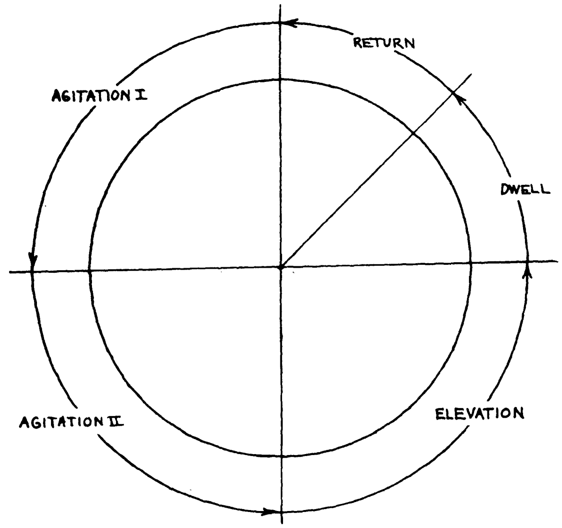


Fig. 10—Sequence of events.

functions. Initially, the modules together appear to the objects as an upright circumferential wall. As the table rotates, a cam surface below actuates the module by deflecting the curved strip upwards. There are three basic modes of actuation: (a) agitation, (b) elevation, and (c) dwell. In the agitation mode, the cam deflects the strip slightly and then allows it to return to the undeflected position. The slight deflection is enough to cause about half the height of the short wall section to protrude above the turntable surface from the gap between adjacent modules (Fig. 8). This protrusion tends to break up bridges and arrange objects in front of the module step. In elevation, the cam deflects the strip fully to the horizontal position as shown in Fig. 9. When the strip is horizontal, the dowel projects its entire length above the table surface and lifts the object above it to the same level as the top of the step. The dwell mode, which follows the elevation mode, simply keeps the strip horizontal, thus insuring that the object will have enough time to move into the pocket area. The cam which actuated the rollers is made up of a series of 75 mm wide arcs of 24 gauge sheet metal butted together to form a continuous surface. Supports at different heights create the contours, allowing two sections of agitation, an elevation, and a dwell area (Fig. 10). The section marked return denotes a transition section where the cantilever spring is returned to its undeflected position. The cam contours were designed to give an agitation frequency of 2 Hz and an elevation time of 0.5 s for a table rotational speed of 30 rpm. Video tapes with the camera rotating with the table were taken to view the module action.

The information gathered about the second module design was very encouraging. The video tapes showed a consistent filling of the pockets after elevation occurred. In most of the trials, by the time the module bank got to the first agitation section following elevation, all the pockets were filled (Fig. 11). At this point in the development, no provision was made for emptying the pockets because the goal of this final portion of the project was to demonstrate the feasibility of the concept only. The trials were done at rotational speeds of 30 to 40 rpm, which would correspond to approximately 2000 walnuts/min (range = 1700-2300). If the speed was lower than 30 rpm, few walnuts entered the pockets, and if above 40 rpm, premature entry occurred.

Some potential problems were noted also. If a pocket became filled before the module got to the elevation section, a multiple walnut exit was likely to occur. In this case, when elevation takes place, the walnut that is lifted from the table surface is unable to move radially into the pocket, hence it remains at the pocket level supported by the surrounding walnuts and the step ready to leave the singulator following the walnut properly located in the pocket. This premature entry was seen to occur from the initial surge of walnuts after their release from the feeding enclosure mounted on the turntable. A second problem related to how the walnuts arranged themselves at the periphery formed by the step. If there had been insufficient agitation to align one walnut in front of each step, two walnuts competed for one pocket, resulting in one filling the pocket and the other occupying a raised position as described above. This problem was also seen to occur, especially after the initial surge of walnuts from the enclosure. Walnuts making up the second row which would go through agitation on the second revolution of the table seemed less prone to this problem. Following the disappearance of the dowel after the first row's elevation, this second row would enter the elevation area in a more "orderly" fashion so that the subsequent agitation did a more thorough job of aligning the walnuts in front of the modules. This indexing or "competition" problem may also be caused by boundary effects owing to the fact that the enclosure forms a rigid wall around the small bank of modules and prevents some circumferential movement of the walnuts. In a prototype with many more modules, it is likely that this problem would be greatly reduced. The results of the indexing tests lends credence to this.

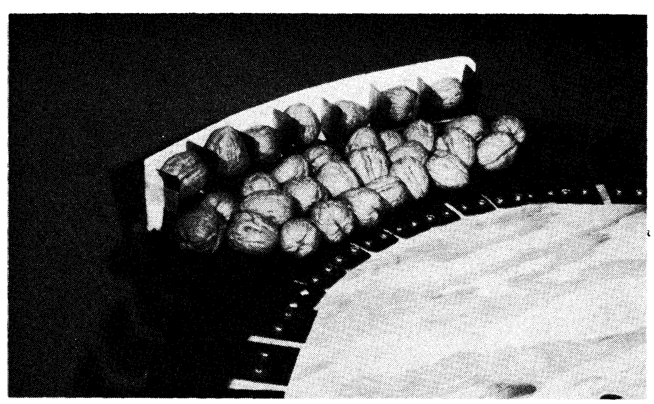


Fig. 11—Correct prototype operation.

Some walnuts experienced difficulty in leaving the elevation area to enter the pocket during the elevation/dwell phases. This occurred because the gap between the elevated dowel and the step tended to "cradle" the walnuts. The gap and the curvature of the walnut introduces an additional "step" the walnut must overcome on the order of 1.2 to 2.5 mm. Calculations show that a step 1.1 mm high is sufficient to prevent a cylinder of like diameter from accelerating radially on a rotating surface similar to the prototype. Thus, when this cradling occurs, it is possible that the centrifugal forces will be insufficient to accelerate the walnut into the pocket. To correct this, the dowel should be lengthened so that when fully elevated it projects about 3 mm above the step. Another approach would be to move the dowel further out on the spring strip and modify the support so that the dowel is about 6 mm closer to the step when fully elevated.

CONCLUSIONS

The second module design is a substantial improvement over the first one. First, it takes advantage of the dynamic effects of rotary motion, more so than the first design. Second, it is mechanically simpler. The motion the cam must impart to the module is only a vertical, up-and-down motion as opposed to the more complex rotation in the first design. Third, the multiple exit problem which plagued the first design is less pronounced with the second.

The project has met the goals established at its beginning; namely, the designs that were developed, particularly the second, have capitalized on the qualities of the first rotary singulator and extended its capabilities to easily handle variations in commodites. The key to the sought after versatility is the modular configuration of the mechanisms that performs the four basic functions of agitation, gating, pocket formation, and exit. Though only a partial prototype has been constructed, the model has satisfactorily demonstrated the potential of the latest design. It is evident that this design is less sensitive to object size variations and is more amenable to the accommodation of a variety of objects by altering the circumferential spacing of the modules or by changing to a different type of module altogether.

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